Bellcomm
955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: September 17, 1971

to: Distribution

from: J. W. Powers

B71 09015

subject: Thermal Considerations Relating to Planned Skylab Momentum Desaturation Maneuvers
Case 620

ABSTRACT

Maneuvers conducted in an interval centered near orbital midnight are planned for the Skylab Orbital Assembly to remove control moment gryo bias momentum. With large absolute values of the angle (β) between the orbital plane and the earth-sun line, a portion or all of the momentum desaturation maneuvers will be performed in sunlight. Illuminated desaturation maneuvers will expose to direct sunlight spacecraft components which are normally shaded in the solar inertial (SI) attitude.

This memorandum evaluates the thermal effects of these momentum desaturation maneuvers on the ATM charger battery regulator modules, OWS radiator and AM-MDA radiator. The analysis is based upon comparisons of incident and absorbed thermal environmental loads on these components during the fully illuminated maneuvers and during the normal SI attitude.

This analysis indicates that for the listed components the thermal effect of fully illuminated momentum desaturation maneuvers is less severe than the normal SI attitude for low $|\beta|$.

[redacted]

(NASA-CR-123222) THERMAL CONSIDERATIONS RELATING TO PLANNED SKYLAB MOMENTUM DESATURATION MANEUVERS (Bellccmm, Inc.) 17 p

N79-72418

Unclas
00/18 12127

FF No. (NASA CR OR TMX OR AD NUMBER) (CATEGORY)

[redacted]

Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

B71 09015

date: September 17, 1971

to: Distribution

from: J. W. Powers

subject: Thermal Considerations Relating to Planned Skylab Momentum Desaturation Maneuvers
Case 620

MEMORANDUM FOR FILE

INTRODUCTION

Maneuvers conducted in an interval centered near orbital midnight are planned for the Skylab Orbital Assembly to remove control moment gyro bias momentum. For absolute values of the angle (β) between the orbit plane and earth-sun line >40°, these momentum desaturation maneuvers will expose spacecraft surfaces which are normally shaded in the solar inertial (SI) attitude to the sun. With increasing $|\beta|$, an increasing fraction of the desaturation maneuver is performed in sunlight. All of the desaturation maneuver is illuminated for $|\beta| \geq 69.4°$.

These maneuvers cause the three shaded ATM charger battery regulator modules (CBRM) surfaces and the OWS radiator, which in the normal SI attitude are parallel to the sun's rays, to receive direct solar flux. This memorandum evaluates both the orbit averaged total incident thermal environmental loads and the maximum absorbed instantaneous loads on these surfaces during fully illuminated maneuvers. These induced thermal loads are compared with the orbit averaged maximum normal earth reflected (albedo) and earth emitted (IR) loads experienced during regular SI attitude mission phases.

DESATURATION PROFILE

The desaturation maneuver flight profiles used in this study are reported in Reference [1]. These profiles were obtained by a simulation of vehicle dynamics, disturbance torques, and dump procedures as defined in the Program Definition Document of November 1970 and modified by a working note from H. Kennel of MSFC.

These dump maneuvers require a minimum 108° of orbital travel when a portion or all of the maneuver is illuminated. With $|\beta|<40°$, a longer totally shaded β dependent maneuver interval is utilized. The maneuver interval is not centered on orbit midnight, but is offset a β dependent angle (η_{TM}, Reference [1]) opposite to the direction of travel in the orbit. In the nominal SI attitude the OWS longitudinal axis is displaced out of the orbital plane by a β dependent rotation ν_Z about the ATM sun pointing axis.

The desaturation profile consists of three consecutive rotations about three different axes. The magnitudes of these constant angular velocity rotations and the axes direction cosines are also β dependent. These rotations and their directions for several β angles are given in Reference [1]. The first and third rotational phases each comprise one fourth of the total maneuver time. At the end of the desaturation maneuver final rotational phase, the Skylab is returned to the original SI attitude for that particular β.

SURFACES OF INTEREST

The three ATM CBRMs utilize passive thermal control and are mounted on the ATM rack. In the SI attitude these modules are shaded by the ATM solar shield and their respective face normals are also perpendicular to the earth-sun line. In this discussion these modules are identified as C_1, C_2, and C_3 and the normals to their respective faces are in the Skylab +Y, +X, and -Y directions. The Skylab -Z axis is the ATM sun pointing axis and the -X axis is the longitudinal axis in the direction of the Workshop aft end.

The Orbital Workshop (OWS) radiator, which is approximately normal to the Skylab -X axis, is another component which may be affected by the thermal consequences of these desaturation maneuvers and is also considered here. In this analysis the directions of the normals to the OWS radiator and C_2 surfaces are both assumed to be parallel to the Skylab longitudinal axis.

The cylindrical AM-MDA radiator is another component whose thermal performance may be adversely affected by the CMG momentum desaturation maneuvers. The axis of this structure coincides with the Skylab X axis.

ANALYSIS

In order to make a thermal evaluation of the effect of desaturation maneuvers upon particular spacecraft surfaces, their respective incident direct solar, albedo and IR heat flux-time profiles must be determined. Available heat flux programs can handle any inertial or planet oriented spacecraft attitude for a complete orbit, but do not have the capability to vary an attitude within an orbit. To determine the time varying direct solar flux requires calculation of the cosine of the angle between the normal to a surface of interest and the solar pointing vector. Evaluation of certain elements of a time dependent 3 x 3 cosine matrix yields the required quantities. This matrix is the product of two, three, and four cosine matrices for the three desaturation maneuver phases.

Accurate determination of the earth emitted thermal flux (IR) during the maneuver is more involved than for the incident direct solar flux. For the IR flux a separate program run must be made for each desired point in the orbit, or the existing GSFC flux program[2] must be modified to provide attitude change capability during an orbit. Fortunately the angular rotations experienced by the vehicle during the desaturation maneuvers are relatively small and the IR flux change will be small.

During the desaturation maneuvers the solid angles from Skylab surfaces to the earth subtend primarily night areas on the earth's surface. The incident earth reflected (albedo) flux on any vehicle surfaces during the maneuvers will thus either be zero or a negligible amount.

Shadowing of the CBRM surfaces during desaturation maneuvers by the ATM solar arrays and the ATM solar shield introduces further significant geometric complexity to the thermal evaluation, especially for the IR and adjacent surface reflected and emitted fluxes. In this analysis the effects of CBRM shadowing and adjacent surface reflected and emitted flux during desaturation maneuvers were not evaluated. The shadowing effects on IR and adjacent surface reflected and emitted flux by the small rotations ($\approx$10°maximum) of the maneuvers were assumed to be constant for the SI and desaturation flight profiles.

The orbit averaged albedo and IR fluxes on the three CBRM surfaces and the OWS radiator surface in the SI attitude are shown as functions of β in Figures 1 and 2.* These curves for a 235 NM circular orbit were determined by use of the GSFC flux program.

*For $-\beta$ angles the C_1 and C_3 albedo curves of Figure 1 are interchanged. The curve for C_2 in this figure is unaffected by $\pm\beta$.

The effect of the rotation of the OWS longitudinal axis about the sun pointing axis and out of the orbit plane (angle ν_z, Reference [1]) during the SI attitude is negligible as shown below and is not included in these curves. The following table lists the orbit averaged albedo (Q_A) and IR (Q_{IR}) fluxes both with and without the ν_z rotation for the CBRM faces for certain β-angles. All fluxes in this analysis are in Btu/hr-ft^2 units.

TABLE I

	SI orbit averaged fluxes ignoring ν_z			SI orbit averaged fluxes considering ν_z		
SURFACE	*$\beta°$	Q_A	Q_{IR}	**ν_z	Q_A	Q_{IR}
C_1	+73	8.5	23.9	-19	8.3	23.9
C_2	+73	4.0	24.4	-19	5.4	24.4
C_3	+73	0.5	23.9	-19	0.7	23.9
C_2	0	13.3	24.4	-1.3	13.0	24.5
C_1	+40	16.8	21.3	-5.5	16.8	21.4
C_2	+40	10.1	24.5	-5.5	9.4	24.4
C_3	+40	2.6	21.3	-5.5	2.6	21.4
C_1	-73	8.5	23.9	+17	8.3	23.9
C_2	-73	4.0	24.4	+17	5.2	24.4
C_3	-73	0.5	23.9	+17	0.6	23.9

To determine the orbit averaged direct solar flux on the surfaces of interest during the desaturation maneuvers, normal vectors were defined with respect to the Skylab body axes. With the vehicle in the SI attitude and the OWS longitudinal axis in the orbital plane, these surface vectors were rotated

*β is positive when the sun is north of orbit noon.
**Rotation sense with respect to the sun-pointing (-Z) axis, Reference [1].

in conformance with the required desaturation maneuver profiles. Two, three and four rotations corresponding to the first, second and third phases of the desaturation maneuver are required. The first rotation for each phase is ν_z about the ATM sun pointing axis and each successive phase utilizes the rotations of the preceeding phase(s). The cosine matrix describing a general rotation of a vector about an arbitrary axis developed in Reference [3] was used to establish the time varying positions of the surface normals with respect to the sun pointing vector. Certain elements of the resulting three transformation matrices are the direction cosines of the angles between the normals to the surfaces of interest and the sun pointing vector.

Figures 3 and 4 show the cosine of this angle during the desaturation maneuver for two of the CBRM normals for $\beta = +/-73°$. Since the OWS radiator panel normal and the remaining CBRM normal are 180° away from the two indicated normals, their curves are simply the mirror images of the illustrated curves. Negative cosine values of these curves indicate that the normal to a particular panel is >90° away from the sun pointing vector. With a negative cosine the surface is thus self shadowing and receives no direct solar flux for that portion of the desaturation maneuver.

The worst case for maximum direct solar flux for a particular CBRM surface occurs for that segment of a curve which exhibits maximum area above the horizontal axis. The corresponding direct solar fluxes on CBRM faces C1 and C3 are seen to be negligible for $|\beta|=73°$ from Figures 3 and 4. The cosine of the maximum angle between the C_2 panel normal and the solar pointing vector for $|\beta|=73°$ is 0.180 from Figure 4. The corresponding time during which C_2 receives direct solar flux is 15.9 minutes. The respective average incident direct solar fluxes during the maneuver and during the orbit for C_2 are 429 x 0.180/2 and

$$429 \times 0.180 \times 15.9/(2\times91.8)=6.7 \text{ Btu/hr-ft}^2.$$

DISCUSSION

In long duration missions, β-angles which yield fully shaded desaturation maneuvers occur much more frequently than do the β-angles which yield partially or fully illuminated maneuvers. From Figure (1) of Reference [4], about 68 days of the indicated 236 day mission will yield some illumination during the desaturation maneuvers. Reference [4] also shows that there will be at least four days during any 236 day mission when every Skylab dump maneuver will be totally illuminated, independent of the SL-1 launch date/time.

Table II lists the orbit averaged incident fluxes for three limiting CBRM cases: maximum $|\beta|$ with maximum orbit averaged direct solar flux (Q_S), minimum β, maximum orbit averaged albedo flux (Q_A) during fully shaded desaturation maneuvers.

TABLE II

Surface	Orbit	$\beta°$	Q_S	Q_A	Q_{IR}
C_2	SI+ desaturation maneuver	-73	6.7	5.2	24.4
C_2	SI	0	---	13.0	24.5
C_1		+40	---	16.8	21.4

Fully shaded desaturation maneuvers occur for the last two cases and the orbit averaged albedo flux is 9% and 41% greater than the sum of the orbit averaged direct solar and albedo fluxes for fully illuminated desaturation maneuvers at maximum $|\beta|$. For the maximum $|\beta|$ case, Q_A and Q_{IR} are from Table I since the small angles of the maneuvers will not yield significant changes to the fluxes as compared with the SI attitude.

For totally illuminated desaturation maneuvers the maximum direct solar flux occurs somewhat prior to orbital midnight. The albedo flux reduces to approximately zero from 90° to 110° of orbital travel from local noon for $|\beta| \leq 73°$. The IR flux on C_1 and C_2 is either a minimum or a low value at the position of maximum direct solar flux for $|\beta|=73°$. The incident direct solar flux from the desaturation maneuvers is therefore a maximum at the time the albedo flux is zero and the IR flux is zero or a low value. The direct solar, albedo and IR fluxes for $\beta = -73°$, when maximum direct solar flux occurs during desaturation maneuvers, are shown in Figure 5 for CBRM C_2.

The direct solar flux received by the considered components as a consequence of the desaturation maneuvers in total illumination will thus occur when they are each close to their respective coolest states.

On an orbit averaged basis, the maximum incident flux is less for an orbit at maximum $|\beta|$ while performing the desaturation maneuvers than for normal SI orbits at low $|\beta|$. A comparison of the maximum instantaneous absorbed thermal loads for the two flight profiles is presented here. The instantaneous absorbed thermal load, Q, is

$$Q = \alpha(S|\cos\lambda| + Q_A) + \varepsilon Q_{IR}$$

where α is the degraded solar absorptance of the CBRM S13G paint (0.5).

ε is the thermal emittance of the CBRM paint (0.9).

$|\cos\lambda|$ is the maximum value of the cosine of the angle between the sun pointing vector and the normal to a CBRM panel from Figures 3 or 4.

$Q_{A,IR}$ are the instantaneous values of the albedo and IR fluxes corresponding to the spacecraft position for $|\cos\lambda|$, (Btu/hr-ft^2).

S is the solar constant (429 Btu/hr-ft^2).

From Figure 4 the maximum value of $|\cos\lambda|$ is 0.180 for C_2 at $\beta = -73°$. This value occurs at 135° from orbit noon in the direction of orbit travel where Q_A=0 and Q_{IR}=0.20. the maximum absorbed instantaneous thermal load for this high $|\beta|$ case from the above equation is 38.8 Btu/hr-ft^2. For CBRM C_1 in a normal SI orbit with β=40°, the maximum absorbed instantaneous thermal load occurs at orbital noon and is 68.5 Btu/hr-ft^2. The maximum instantaneous load absorbed by C_1 during a normal SI orbit or a shadowed desaturation orbit maneuver with β=40° is thus 91% higher than the maximum absorbed by C_2 during a desaturation orbit with $\beta = -73°$. Here, as in the previous analysis, the change in the incident IR and adjacent surface reflected and emitted fluxes due to the different shadowing pattern resulting from the small rotation (10°24') is neglected.

The previous CBRM arguments are also appropriate for the OWS radiator, since its normal is approximately 180° away from C_2. By considering the reflected C_2 curves of Figures 3 and 4, the maximum incident orbit averaged direct solar flux on the OWS radiator (4.5 Btu/hr-ft^2) for maximum $|\beta|$ is less than for C_2.

In the SI attitude the AM-MDA radiator axis is normal to the earth-sun line with the majority of the sun facing surface shaded by the ATM solar shield and solar arrays. Vehicle rotations other than about the sun pointing axis may cause additional radiator surface to be exposed directly to the sun. If the amount of additional radiator surface exposed to the sun during a desaturation maneuver is not significant, the rotation is beneficial since all incident orbit averaged environmental fluxes on the developed radiator cylinder are decreased. If the vehicle is rotated so that the angle between the ATM axis and the sun-earth line is 15°, the orbit averaged fluxes on the AM-MDA radiator surface will be reduced as follows: direct solar and albedo, 3.4%:IR, 1.8%.

The effect of β on the incident AM-MDA radiator albedo flux during the normal SI attitude mission is significant. At $\beta = 0$, the orbit averaged albedo flux on the radiator developed surface is 21.9 Btu/hr-ft^2. For $|\beta|$ increased to 35° and 73°, the respective orbit averaged albedo fluxes decrease respectively to 10.5 and 3.9 Btu/hr-ft^2. The radiator cylinder is illuminated during the desaturation maneuvers only at high $|\beta|$, at which time the albedo flux has significantly reduced. At the small rotation angles ($\approx$10°) experienced during the maneuver, this reduction of the albedo, direct solar and IR fluxes should dominate any increases in illuminated radiator surface. It is thus reasonable to conclude that the nominal SI attitude at low $|\beta|$ presents a more severe thermal case for the AM-MDA radiator than does the fully illuminated desaturation maneuvers at high $|\beta|$.

CONCLUSIONS

The thermal effects of the proposed Skylab CMG momentum desaturation maneuvers on the three CBRM modules, the OWS radiator and the AM-MDA radiator were evaluated. These evaluations were based upon comparisons of total thermal orbit averaged environmental loads with the vehicle executing the maneuvers in a fully illuminated orbit and with the vehicle in the normal SI attitude. Maximum instantaneous absorbed thermal load for the two types of flight profiles were also compared. This analysis shows that the thermal effect of these maneuvers at high $|\beta|$, when the orbit is completely illuminated, is less severe than the normal SI mode at low $|\beta|$. The desaturation maneuvers as presently proposed should thus present no thermal problems to the components listed. Implicit in this conclusion is the assumed thermal adequacy of these components to withstand the planned β-angle spectrum of the Skylab mission.

J. W. Powers

1022-JWP-tla J. W. Powers

Attachments
References
Figures 1-4

REFERENCES

1. Levidow, W., Skylab Typical Momentum Desaturation Maneuvers, Bellcomm Memorandum for File, June 1, 1971.

2. Powers, J. W., Spacecraft Shadowing and Thermal Flux Computer Programs with Sample Problems, Bellcomm Memorandum for File, July 8, 1968.

3. Powers, J. W., The Orientation Geometry of General Surface Elements and Solar Vectors, Bellcomm Memorandum for File, Sept. 21, 1970.

4. Radany, E. W., Skylab Daylight Momentum Dump Requirements, Bellcomm Memorandum for File, June 30, 1971.

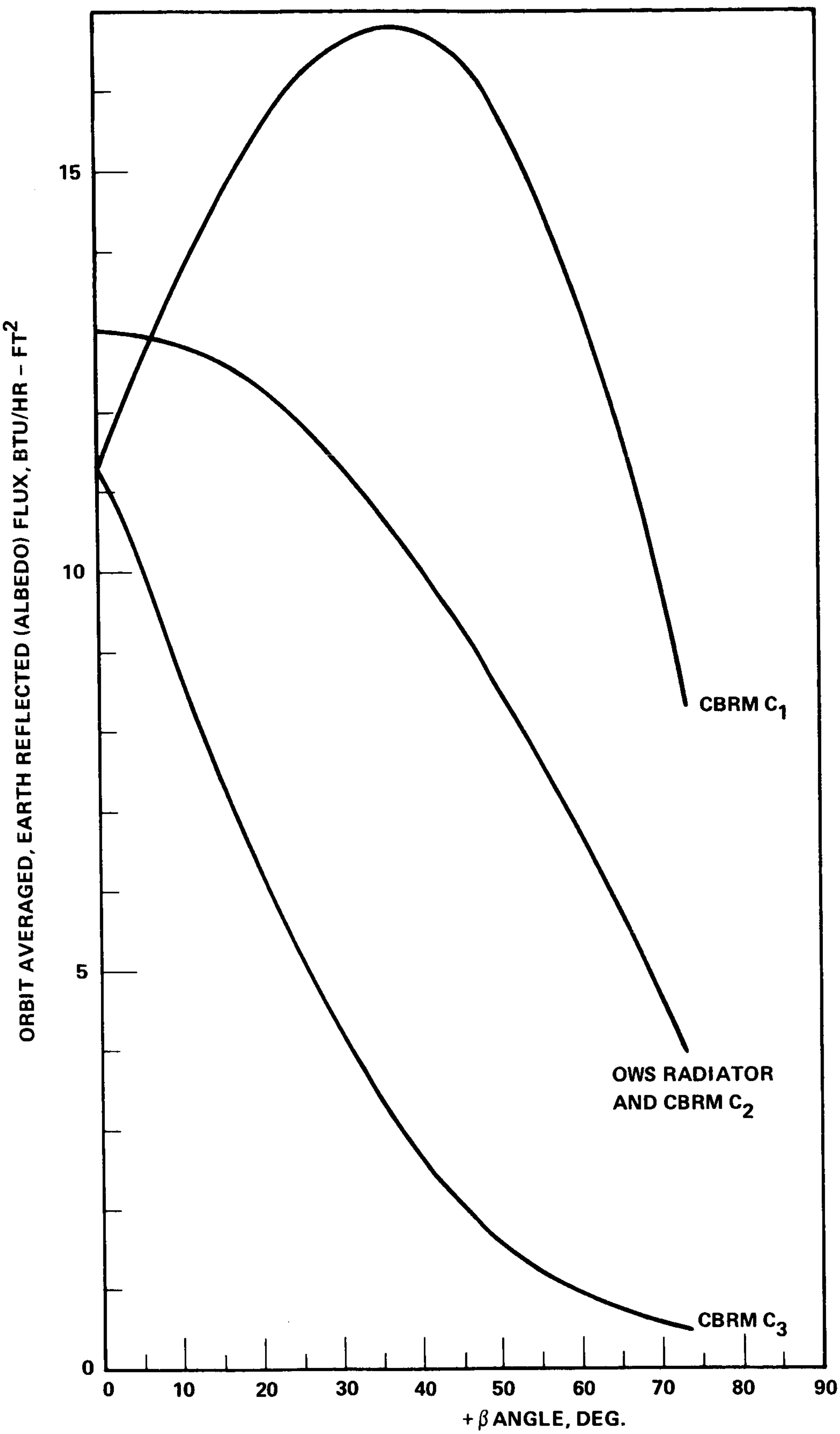

FIGURE 1 - ORBIT AVERAGED ALBEDO FLUX ON ATM CBRM AND OWS RADIATOR SURFACES, SOLAR INERTIAL ATTITUDE, 235 NM CIRCULAR ORBIT

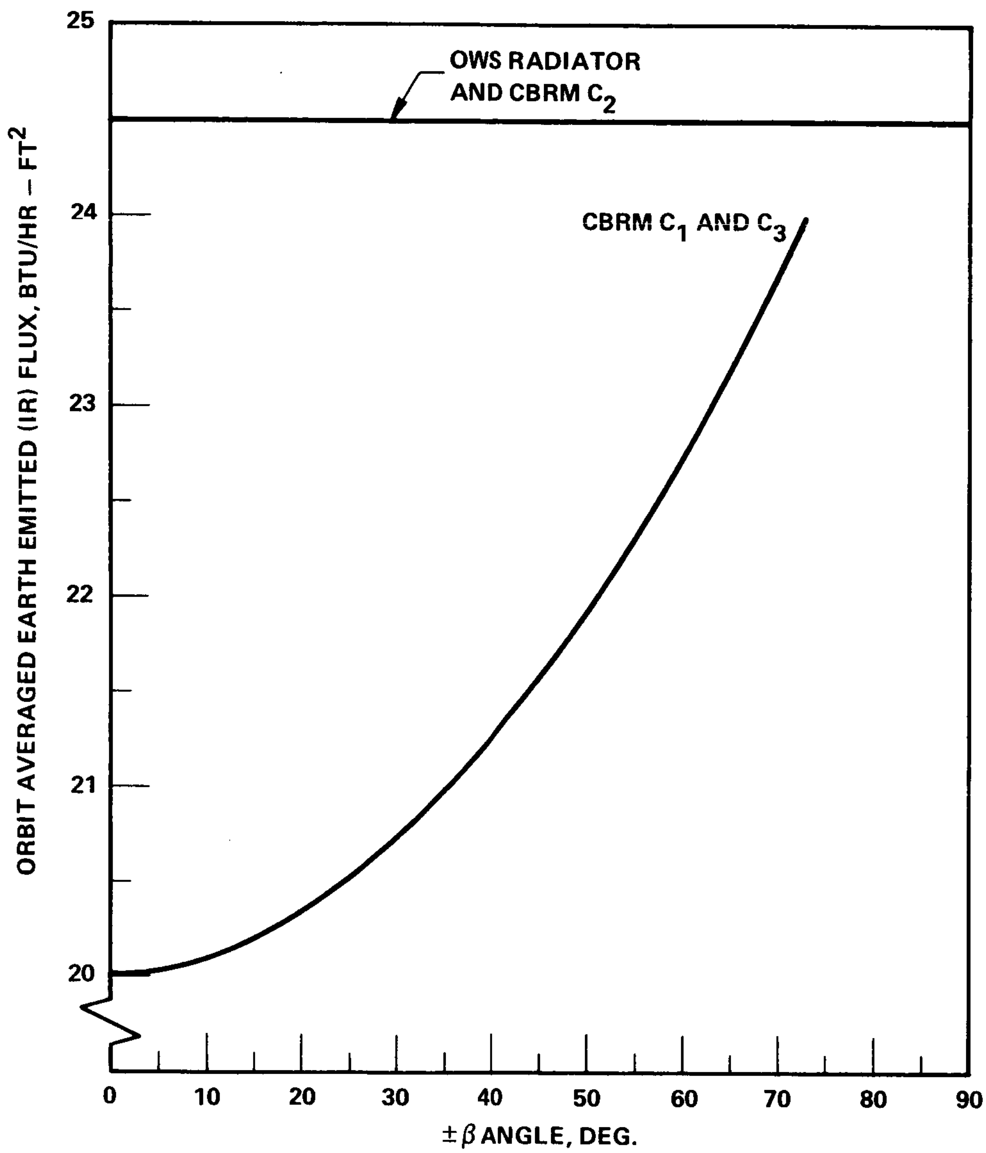

FIGURE 2 - ORBIT AVERAGED IR FLUX ON ATM CBRM AND OWS RADIATOR SURFACES, SOLAR INERTIAL ATTITUDE, 235 NM CIRCULAR ORBIT

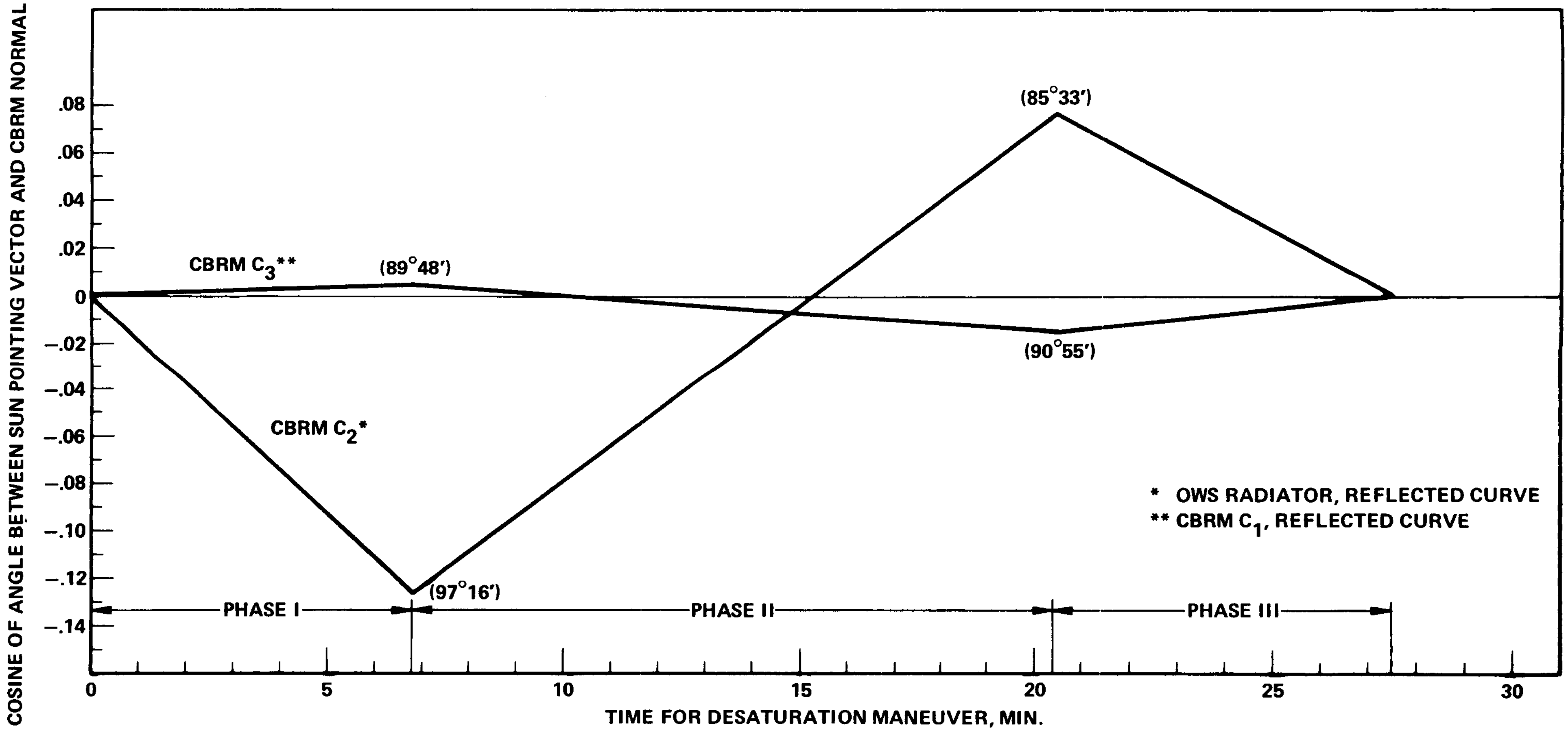

FIGURE 3 - DESATURATION MANEUVER ANGLE VS TIME, $\beta = +73°$, 235 NM CIRCULAR ORBIT

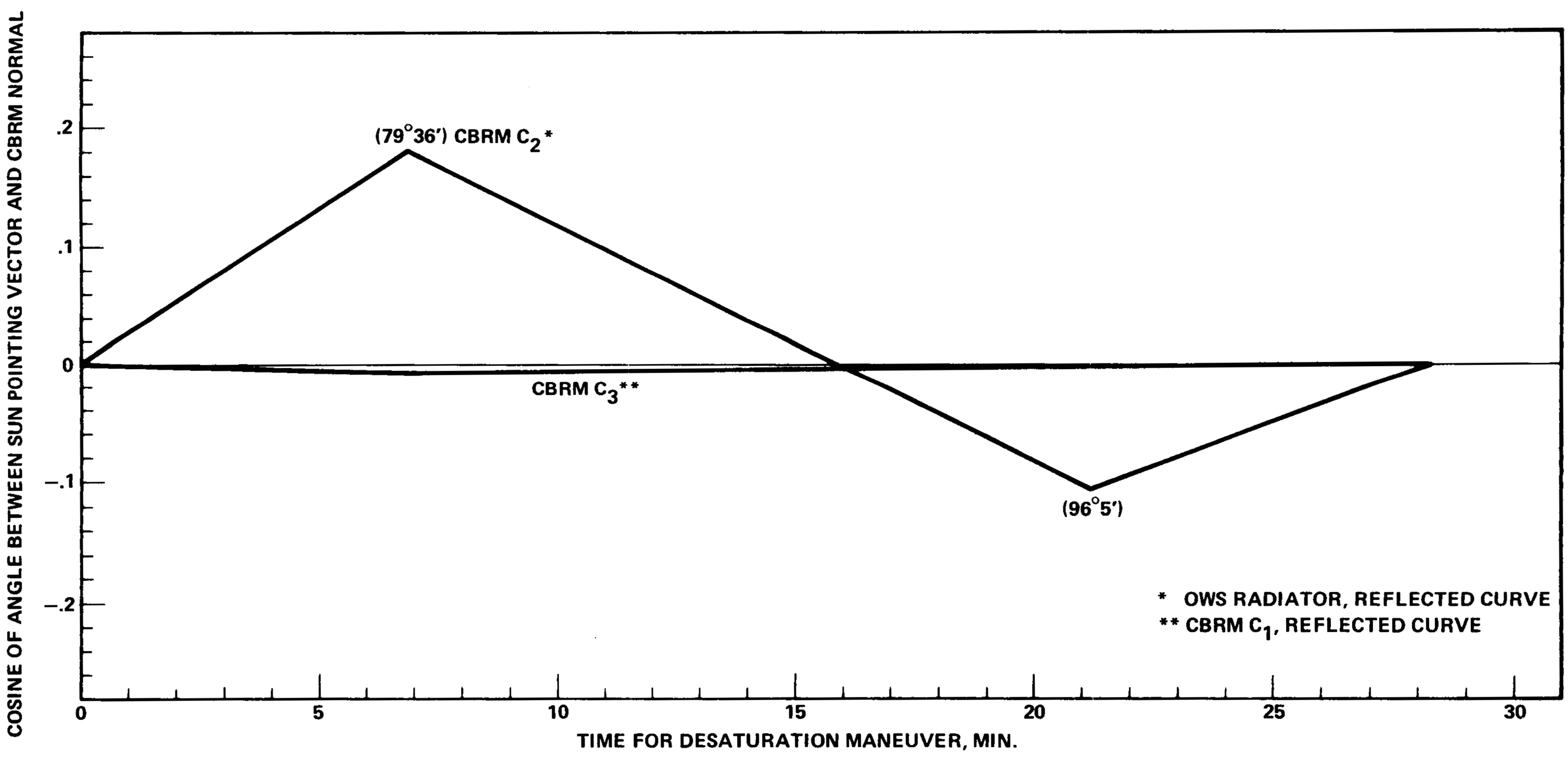

FIGURE 4 - DESATURATION MANEUVER ANGLE VS TIME, $\beta = -73^\circ$, 235 NM CIRCULAR ORBIT

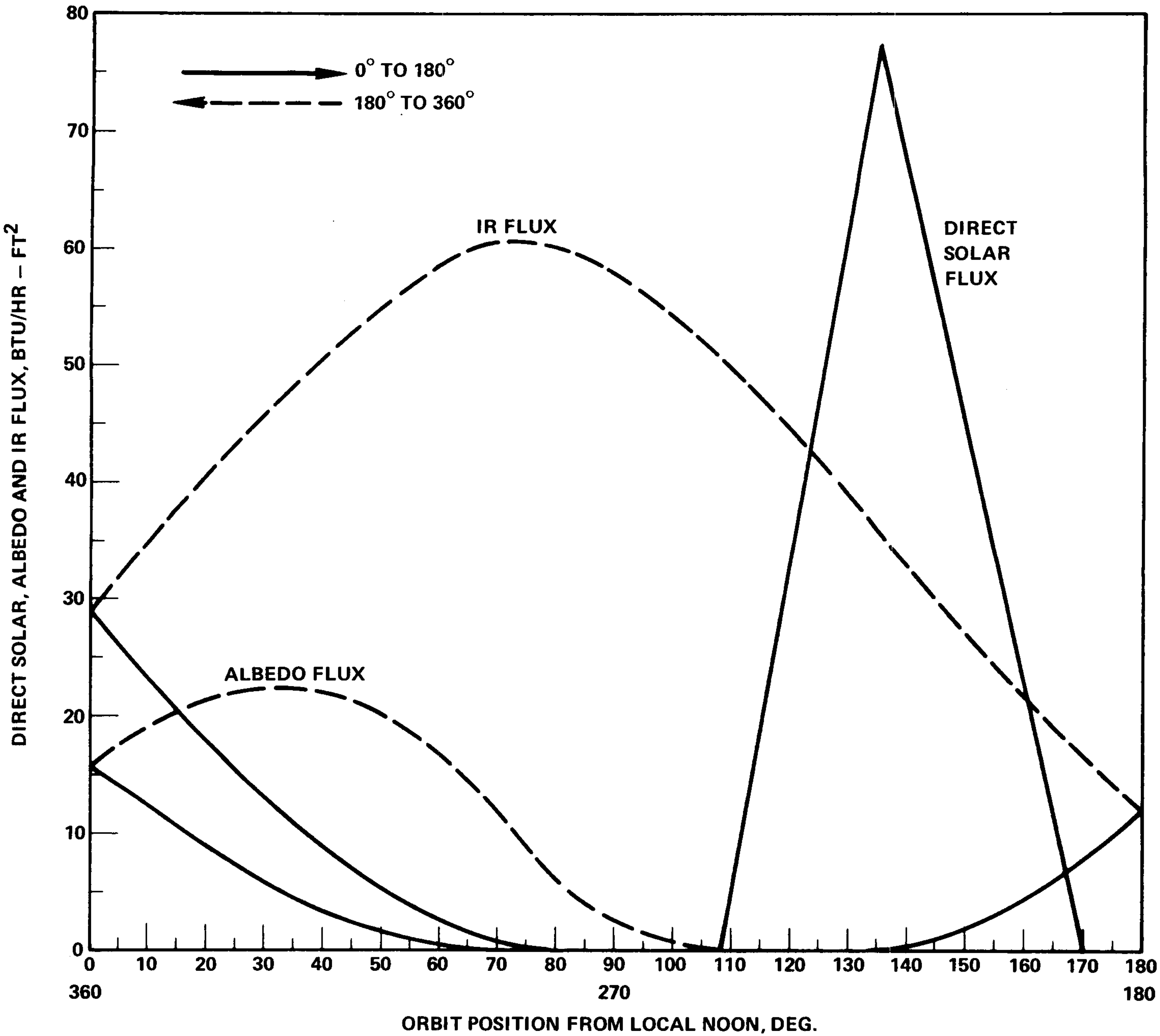

FIGURE 5 - FLUX INCIDENT UPON CBRM C_2 DURING A DESATURATION MANEUVER ORBIT AT $\beta = -73°$, 235 NM CIRCULAR ORBIT

Subject: Thermal Considerations Relating to Planned Skylab Momentum Desaturation Maneuvers - Case 620

Distribution List

NASA Headquarters

H. Cohen/MLQ
J. H. Disher/MLD
J. P. Field, Jr./MLB
T. E. Hanes/MLA
A. S. Lyman/MR
H. Mannheimer/MLA
M. Savage/MLE
W. C. Schneider/ML

GSFC

J. T. Skladany/713

MSC

R. G. Brown/ES-16
E. T. Chimenti/ES-5
R. E. Durkee/ES-5
R. L. Frost/Ks
J. W. Orsag/ES-5

MSFC

G. D. Hopson/S&E-ASTN-PL
J. W. Littles/S&E-ASTN-PLA
J. W. Simms/S&E-ASTN-PTA
R. G. Smith/PM-SAT-MGR
H. F. Trucks/S&E-ASTN-PTA
J. L. Vaniman/S&E-ASTN-PT
C. C. Wood/S&E-ASTN-P

Bellcomm

A. P. Boysen
J. P. Downs
D. R. Hagner
W. G. Heffron
D. P. Ling
J. Z. Menard
J. M. Nervik
P. F. Sennewald
J. W. Timko
R. L. Wagner
M. P. Wilson
Depts. 1011, 1013, 2031, 2034
Supervision
Depts. 1022, 1024, 1025
Dept. 1024 File
Central File
Library